RIC 2010

Next Generation Nuclear Plant (NGNP) Research

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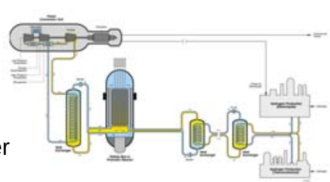
High Temperature Materials of Potential Concern

- Pressure vessel steels
- Alloys for heat exchangers
- Control rod sleeves and other core internals



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Specific Questions That Are Being Addressed

- For some systems are suitable materials available at all?
- If materials are available do we know enough to support standards (ASTM), codes (ASME) and NRC license?
- Can anybody manufacture what we need?
- Can we get it all done in time to meet the schedule?

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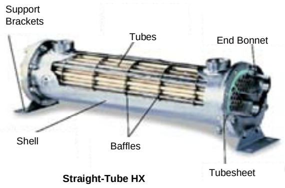
Proposed Heat Exchanger Concepts

- Might see temperature up to 950˚ C
- Creep fatigue is expected damage mechanism
- Only one alloy 800H is Code qualified and only to 762˚ C



Straight-Tube HX

(Photo From API Heat Transfer)

(Courtesy Heatric)

Printed Circuit Board Heat Exchanger

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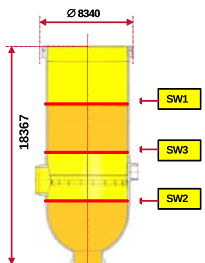
Issues Being Addressed For The Reactor Pressure Vessel

- Conventional light water reactor vessel steels must operate below 371˚ C
- Grade 91 steel offers potential for higher temperature operation – but increases technical difficulties
- On-site fabrication, transportation and long term aging are issues



RPV On-site Weld Locations

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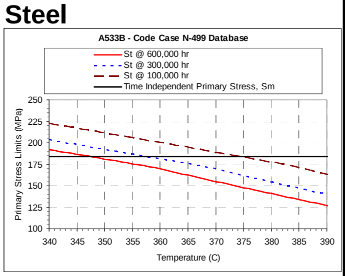
ASME Code Rules for Conventional Pressure Vessel Steel

- Code Section NB allows A508/533 steel up to 371˚ C with negligible creep
- Code Case 499 established time dependent stresses which indicate significant creep below NB limits



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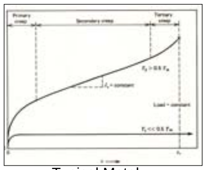
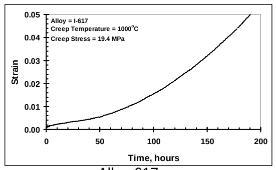
Creep Behavior of Alloy 617



Typical Metal

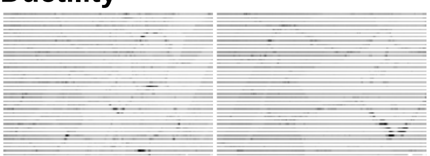


Alloy 617

- Alloy 617 creep behavior not well described by conventional model
- Creep cavitation is initiated at strain of about 10%

Aging, Microstructure Stability and Ductility

Stress Axis

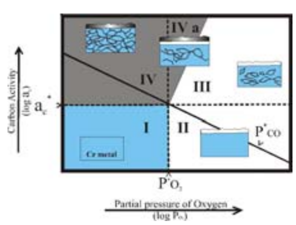


•Aging under load results in carbide redistribution and cavitation

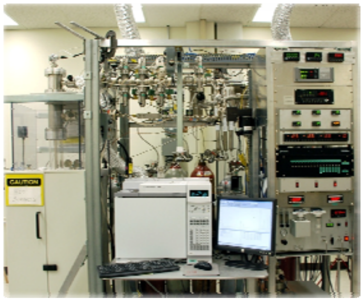
•Thermal aging can result in precipitation of additional phases

Environmental Effects

- There is no NGNP chemistry that is inert with respect to Ni based alloys
- Program activity is focused on determining acceptable range of operating chemistry for primary NGNP He



Controlled Chemistry Test Loop



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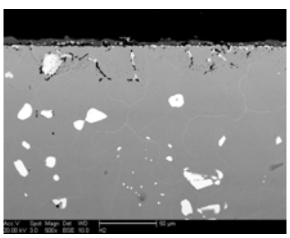
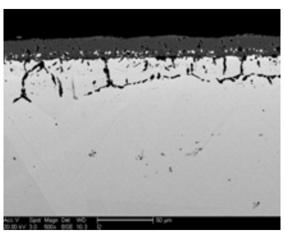
Alloys Exposed to Oxidizing VHTR He at 1000° C



Alloy 230



Alloy 617

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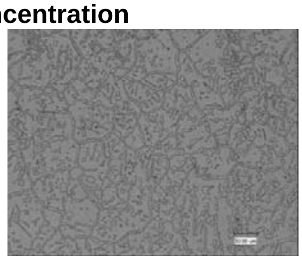
Alloy in He at High Carbon Activity and Low Water Concentration

- No protective oxide is formed
- The alloys are heavily carburized
- Alloy 230 is significantly more prone to carburization



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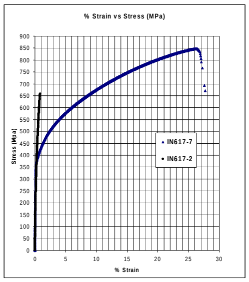
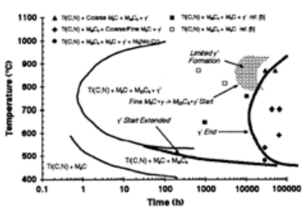
Tensile Curves of Alloy 617 Exposed for 1000 hours at 900° C

- Carburized Alloy 617 specimens exhibited nil ductility at room temperature
- Oxidized Alloy 617 exhibited 26% reduction in area at room temperature
- All of the Alloy 230 specimens were carburized and had nil ductility



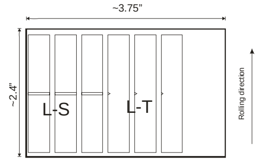
Precipitation During Aging



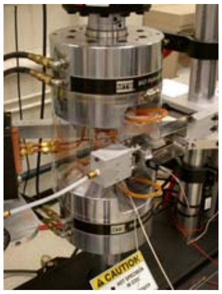
- Long-term aging results in formation of new phases
- Variation in microstructure can affect mechanical properties

Charpy Impact Data for Alloy 617 Aged in Air at 800° C

time (hours L-S)	breaking energy (J)
100	93.8
1000	77.5
5000	40.2
10000	24.7
time (hours L-T)	
100	68.2
1000	61.5
5000	37.5
10000	24.3



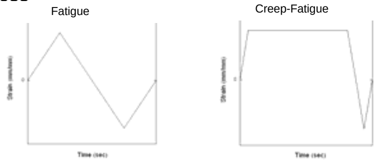
Creep-Fatigue Testing



- Creep-fatigue laboratory
  - Six servo-hydraulic frames
  - Controlled environment capability
  - Temperatures of >1000° C
- Establishing quality level creep-fatigue test procedure
- Creep-fatigue community collaboration
- Universal testing challenges
  - Temperature measurement
  - Serrated yielding and strain control

Low Cycle Fatigue and Creep-Fatigue

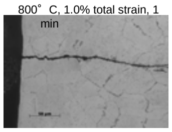
- Strain rate = 10^{-3} /sec
- Fully-reversed strain control
- Data collection is interleaved strain and time
- Peak/valley data collection triggered on strain and stress

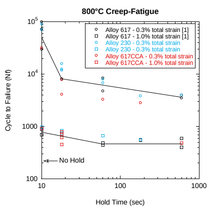


800° C Creep-Fatigue

- Microstructural observations
  - Predominately transgranular crack propagation
  - Intergranular crack propagation at longer hold times
  - Creep cavitation not observed along the grain boundaries for the hold time tests up to 10 minutes

800° C, 1.0% total strain, 1 min

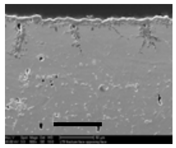


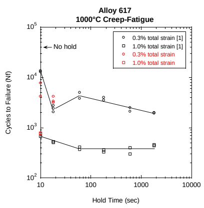


1000° C Creep-Fatigue

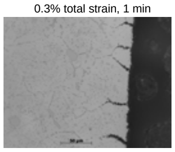
- Microstructural observations
  - Surface cracks initiate at oxidized grain boundaries
  - Intergranular crack propagation
  - Creep cavitation at grain boundaries
  - Grain boundary carbide redistribution in longer hold tests

Alloy 617
0.3% total strain, 3 min

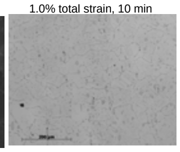




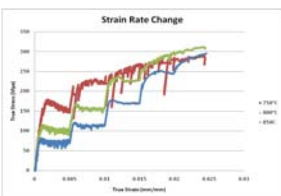
Alloy 230
0.3% total strain, 1 min

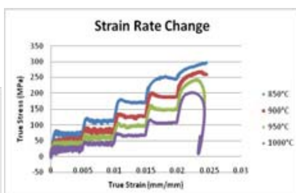


Alloy 230
1.0% total strain, 10 min



Strain Rate Sensitivity of Alloy 617





Summary

- Issues under consideration
  - Proper care to account for Code issues is necessary for license
  - We will have to address impact of welding and heat affected zone on properties to Code qualify alloys
  - There is window of impurity chemistries that will maximize component life
  - There will be unexpected failure mechanisms
- Issues of further concern
  - How do we model creep/fatigue
  - What is the mechanism and impact of dynamic strain aging
  - Is there some clever way to examine negligible creep issue